UNIVERSIDADE DE BRASÍLIA
INSTITUTO DE GEOCIÊNCIAS
CURSO DE ESPECIALIZAÇÃO EM GEOPROCESSAMENTO AMBIENTAL

# AUTOMATED INDEXING AND CATALOGING OF MULTITEMPORAL ORBITAL SAR IMAGES

**José de Paula Rodrigues Neto Assis**

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**Monografia de especialização em Geoprocessamento Ambiental apresentada a banca examinadora do Instituto de Geociências como exigência para a obtenção do título de especialista em Geoprocessamento**

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APRESENTAÇÃO

Este artigo foi apresentado como Trabalho de Conclusão de Curso de Especialização *Lato Sensu* em Geoprocessamento Ambiental, elaborado e redigido por José de Paula Rodrigues Neto Assis, sob orientação da Professora Doutora Tati de Almeida. A decisão de redigir o trabalho em língua inglesa decorreu da pretensão de enviar para publicação em um periódico internacional, também de língua inglesa, o IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing - JSTARS. Também decorre dessa pretensão a formatação fora dos padrões brasileiros (normas ABNT), tanto do documento quanto das citações e referências. Os demais co-autores no texto contribuíram com a elaboração da arquitetura e a implementação do sistema descrito, com a produção dos dados apresentados e com a disponibilização dos mapas. O artigo enfatiza a faceta de banco de dados, de catalogação de imagens, do sistema Sipam SAR, criado sob financiamento do Fundo Amazônia pelo Centro Gestor e Operacional do Sistema de Proteção da Amazônia (Censipam), que tem funcionalidade análoga ao sistema DETER-B, feito pelo Instituto Nacional de Pesquisas Espaciais (INPE) e também descrito no periódico JSTARS, embora o Sipam SAR trabalhe com imagens SAR e resolução espacial diferente.

# Automated indexing and cataloging of multitemporal orbital SAR images

José de Paula Rodrigues Neto Assis, Tati de Almeida, Cristina Aparecida Beneditti, Miguel Archanjo Bacellar Goes Telles Junior, Alex Lopes Pereira, Bruno Alphonsus de Oliveira Nascimento

***Abstract*—This article describes a system for automatically indexing and cataloging multitemporal orbital synthetic aperture radar (SAR) images, such as those acquired by the COSMO-SkyMed satellite constellation, so that they can be used for semiautomatic deforestation detection in the Brazilian Amazon Rainforest. This system is called SipamSAR. Brazilian Instituto Nacional de Pesquisas Espaciais (INPE) has systems that aim to detect deforestation in the Amazon Rainforest: PRODES, DETER and DETER-B. These systems rely on optical imagery, which makes it difficult to observe features under cloud cover. SipamSAR improves on this by using SAR on C and X bands, which negates the impact of cloud coverage and makes it possible to watch for deforestation the entire year. The use of SAR images brings another set of challenges. In order to do automated change detection, images taken from the same ground location must have the same geometry, same orbit direction, same view side (right/left) , same beam. The system stores these attributes (among others) of all received images in a PostgreSQL/PostGIS database, which allow them to be used in a semi-automated change detection system. With this system, large sets of multitemporal data can be processed; changes in forest cover is detected much more accurately than with previous systems. The forest can be monitored year-round, and removal of areas as small as 0.5 ha can be detected.**

***Index Terms*—Database, PostGIS, cataloging, SAR, multitemporal change detection, deforestation, Amazon.**

## I. Introduction

ILLEGAL deforestation in the Brazilian Amazon is one of the most serious problems that afflict that ecosystem. These deforestation actions are result of: increase of population density; expansion of the agricultural frontier, logging, mining [1], creation of clandestine runways. The environmental impacts of these deforestation actions are harmful: reduction of the forest area - with consequent impact on the capacity of carbon sequestration -, desertification, bio-piracy, circulation of Brazilian and foreign criminals.

To monitor the Amazon region, the Brazilian government has an Amazon Protection System (Sistema de Proteção da Amazônia - Sipam), which aims to collect, process and disseminate geographic information from that region. The body responsible for managing this system is the Management and Operational Center of the Amazon Protection System (Censipam), under the Ministry of Defense.

The Brazilian government has a system that monitors the Amazon Forest with optical imaging put in place by the National Institute for Spatial Research (Instituto Nacional de Pesquisas Espaciais - INPE) , called PRODES [2], which pioneered the use of remote sensing for detecting of deforestation in that area. It uses optical imagery from the Landsat constellation of satellites, as well as CBERS-2, CBERS-2B, CBERS-4 (which are satellites that result from a technological cooperation between China and Brazil), the Indian IRS-1 and IRS-2, and the British UK-DMC2. The products from the PRODES program are annual estimates of deforestation in the Amazon, which are then used to find "hot spots" of such activity and on which public policies are elaborated.

In 2016, Censipam began monitoring deforested areas in those hot spots using images generated by orbital SAR, which, because they function in the X-band region of the electromagnetic spectrum, allow the acquisition of images independently of sunlight and with almost no influence of cloud cover.

In order to the deforestation detection work to be carried out with enough time for the authorities responsible for monitoring and restraining criminal actions to act, the collected Single Look Complex (SLC) images are processed and made available to the teams of experts in remote sensing who carry out the work of identifying deforestation. The Brazilian National Institute for Space Research (INPE) has a system in place to rapidly detect deforestation, called DETER-B [3], which evolved from the older DETER. This system uses imagery from AWiFS sensors, which have a spatial resolution of 56 meters, and a temporal resolution of 5 days, in the bands 3 (red, 0.62-0.68μm), 4 (near-infrared, 0.77-0.86μm) and 5 (mid-infrared, 1.55-1.70μm). DETER used MODIS sensors, with 250 meters of spatial resolution in red (0.62-0.72μm) and infrared (0.841-0.876μm) bands, albeit with a better temporal resolution of 1 day. However, in order to increase the accuracy of deforestation detection, higher spatial and temporal resolutions are needed. Also, due to the high incidence of cloud coverage over the Amazon forest in the rainy season, it is necessary to use cloud-penetrating frequencies (such as X and C bands) to maximize the possibility of observation of the soil and the forest canopy.

Thus, with the increased availability of such data, it became possible to build a system that allows the Brazilian government not only to monitor and elaborate long-term policies to fight illegal deforestation, but also to actively stop such illegal activities on the Amazon Forest almost at the same time

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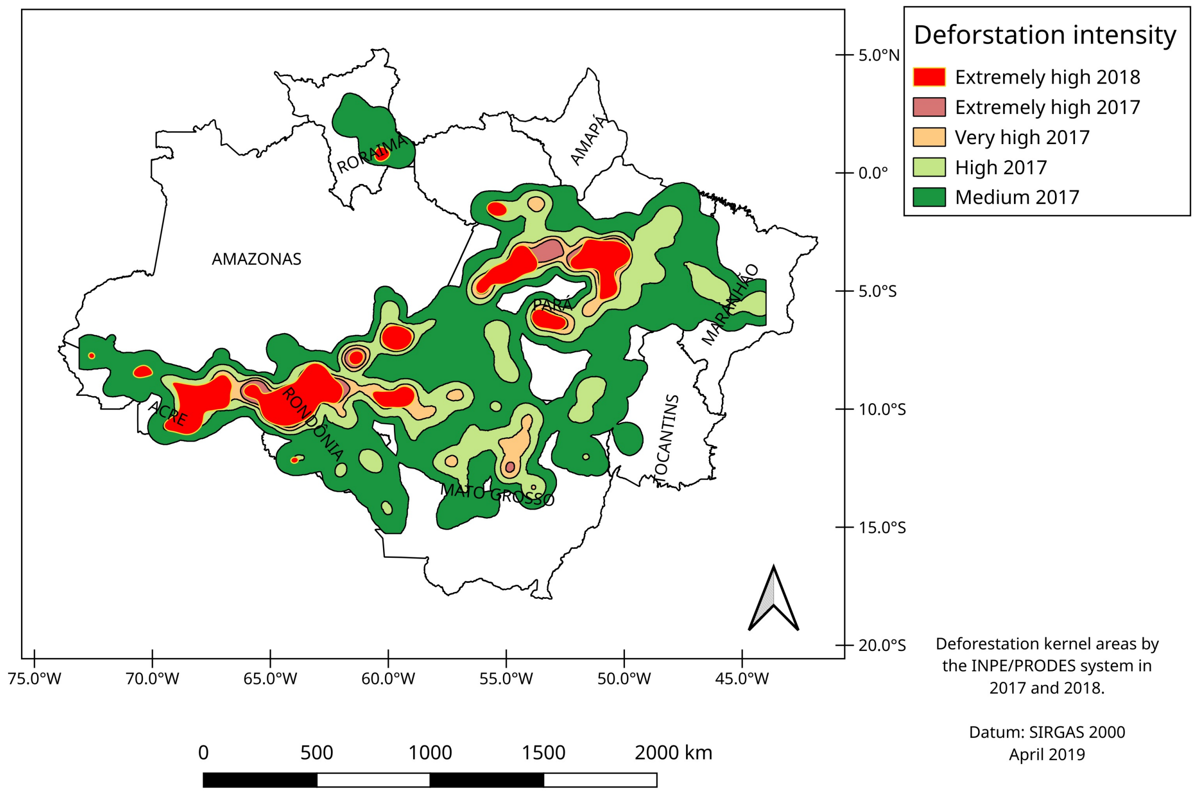


Fig. 1. Sectors of the Amazon monitored by each Regional Office

as they are started. This project is financed by the Amazon Fund [4], which is managed by the Brazilian Development Bank (BNDES). One of its subsystems deals specifically with acquisition, indexing, processing and detection of illegal activities, and is called Sipam SAR.

Censipam, in addition to the General Coordination Center in Brasília, has a presence in the Legal Amazon through the Regional Offices in Belém, Manaus and Porto Velho, each of which has a remote sensing team responsible for monitoring a designated area. Because the volume of data is large, it is necessary to automate the collection, indexing, temporal organization and geographic assignment of these images to the maximum extent possible, so that each team receives a correct set of images according to their assignment.

This work aims to show an integrated system for organizing and processing of orbital radar images using as much as possible free and widely available solutions in the market, such as PostgreSQL database (and PostGIS extension) and libraries for geoprocessing in Python programming language (more specifically, the MetaGETA library, used to extract raster image metadata). The implementation of this system results in the availability of the processed images so as to allow the rapid detection of deforestation and the timely activation of the agencies responsible for the surveillance and protection of the Amazon.

## II. Materials

Images from the COSMO-SkyMed constellation in Hierarchical Data Format, version 5 (HDF5), which contains metadata about the image, a "quick-look" version of the image, and the Single Look Complex (SLC) image data, processed to Level 1A (which results in a Single-look Complex Slant (SCS) image, that contains focused data in complex format, in slant range, zero Doppler projection, as described in [5]).

A storage server with at least 60 TB of available space.

A database server with PostgreSQL version 9.5 or later installed, and with the PostGIS [6] extension installed and configured on the working database.

A headless application server, with a Python version 2.7 environment, bash shell, lftp client, and psql (the PostgreSQL client app) and python-postgresql binding libraries.

Workstations running ENVI+SARscape and IDL scripts running concurrent processing on the SAR images.

Analysts' workstations should use QGIS [7] version 3.4 or later, or other GIS software capable of reading and writing data in the PostgreSQL format.

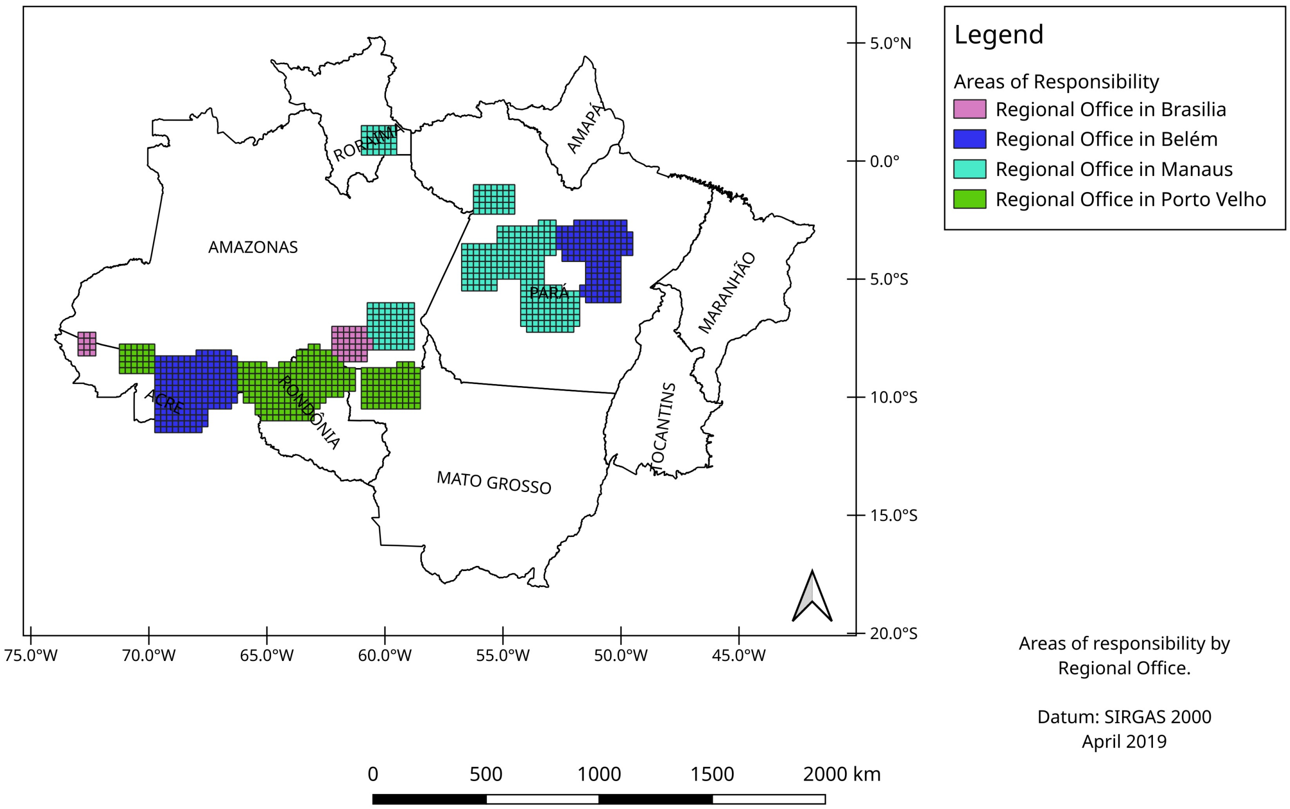


Fig. 2. Sectors of the Amazon monitored by each Regional Office

The database server, storage server and application server all run Linux. The ENVI/SARscape server run MS Windows, and the analysts' workstations may run Windows or Linux.

The scripts and programs communicate among themselves via shared files; that is, each component of the system monitors a previously configured shared network folder for a file (or files) of a specific type and content. The presence of this file is an indicator that the next stage in the processing pipeline can continue.

Target areas for monitoring are determined by the INPE/PRODES program. The areas in which PRODES indicate the most intense degradation are chosen for monitoring. Figure 1 shows the kernel areas in 2017 and 2018. Figure 2 shows the squares that correspond to the BCIM that intersect the hottest spots of deforestation detected by PRODES in 2018, separated by Regional Office.

## III. Data formats and organization

Critical to the processing pipeline of this amount of SAR images is the organization of the database from which the correct data will be retrieved. The database model is simple: a table that registers baseline polygons of deforested areas, which we call tb_t0_desmatamento, and is updated after each cycle of analyzing; a table that stores current deforestation polygons, called tb_desmatamento which is updated after analysis of each SAR image, and feeds the t0 table at the end of the processing cycle; a table that stores data about the retrieved images, and images that derive from the processing of the original ones, including polygon representation of the images' limits, called tb_imagem; a table called tb_responsavel that stores the analysts' data, such as Regional Office, name, and e-mail address; and a table named tb_divisao_amazonia_cim that stores in each record a polygon representation of a section of the International Map of the World (IMW) in a 1:50000 scale and an analyst responsible for that polygon.

Figure 3 shows the attributes as stored in the DBMS. In that figure, the prefix of an attribute indicates its data type. Primary keys are artificial and are prefixed with "co_seq_". Foreign keys from other tables are prefixed with "co_". Attributes whose name begin with "nu_" and "qt_" are numeric; those that begin with "dt_" are dates; those that begin with "st_" are boolean; the prefix "no_" indicates a string type that denotes a name; finally, actual geometric data is stored in fields named "geom" or prefixed with "geom_".

Actual raster files are not stored directly in the database; instead, the file path is stored, and the images are accessed directly from a shared network drive.

Image files from COSMO-SkyMed are, as mentioned, in

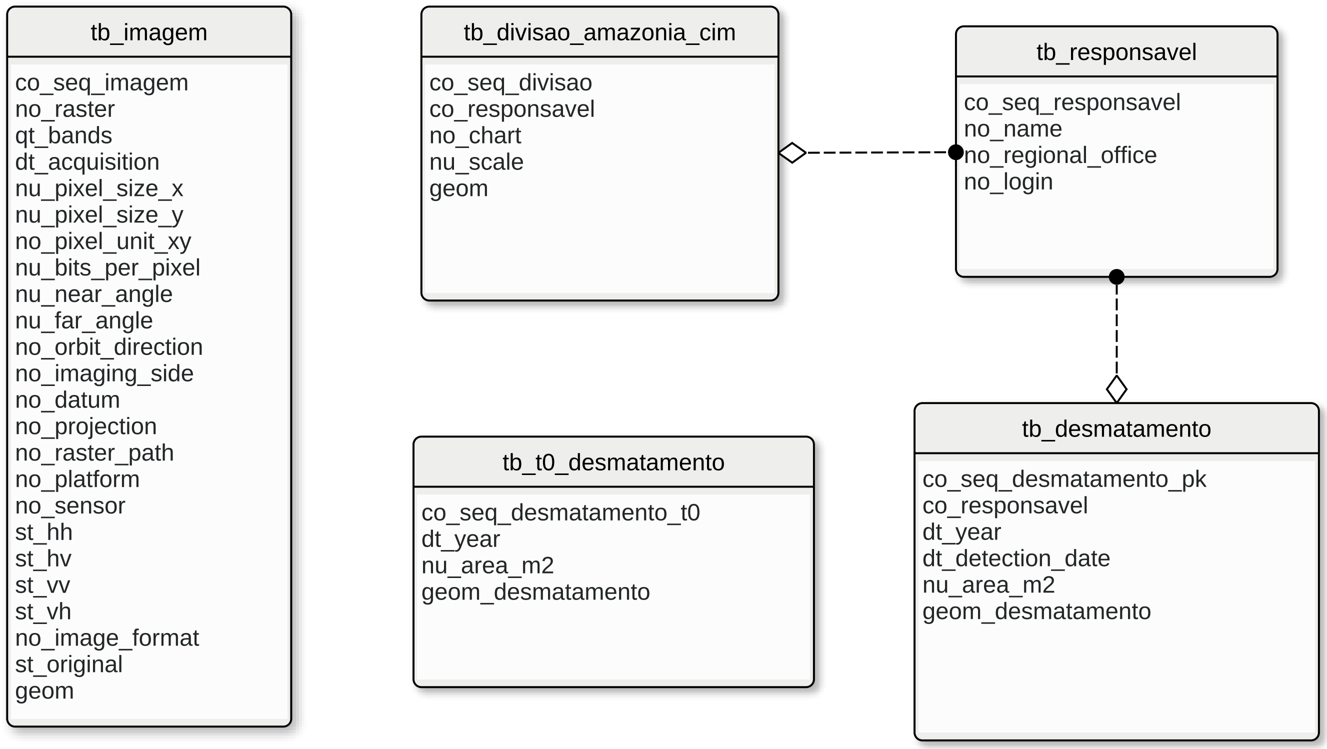


Fig. 3. Database model of the Amazônia SAR processing pipeline

Hierarchical Data Format (HDF), version 5, as specified by [8]. They contain a header that has general information about the satellite transmission and receiving station, radar wavelength (3.1 cm), ground coverage extent, satellite height, sample format (16 bit integer), samples per pixel (2); they have a "quick look" image in low resolution; and the actual raster data in the described format. The actual image raster is in a complex format; it is captured in stripmap mode, and the actual data is stored in a file with BIP (Band Interleaved by Pixel) format, where each "band" is a component (real, imaginary) of the complex sample.

Other raster data formats, such as GeoTIFF, can also be used, as long as they can be read and processed by the change detection processing pipeline. The database system is format-agnostic; it is not important in which format the original data is stored, as long as the relevant metadata - such as orbit direction, image coordinates, geometry of acquisition - can be extracted.

By the same token, data from different satellites, such as Sentinel-1 or RADARSAT can also be used; even optical imagery may be cataloged in this database.

The aforementioned table tb_imagem stores the raster name, the number of bands it is made of (in general, 2 for complex SAR data as already mentioned), the date of acquisition, the size (linear or angular, depending on the origin of the image) of a pixel in the X and Y dimensions, the unit (linear or angular, meters, degrees, feet, radians etc.) of the pixel sizes, the bit depth of each pixel, the near and far angles of acquisition, the direction of the orbit (either ascending - from south to north - or descending - from north to south), the side of the look (either left or right), datum and projection of the polygon that corresponds to the footprint of the image, the number of lines and of columns of the image, the polygon itself in the PostGIS format, the kind of platform (satellite) and sensor (SAR, X-band, C-band, or any other) that was used to acquire the image, flags indicating the polarization: HH, HV, VH, VV, an identification of the underlying raster format (such as GeoTIFF or HDF for instance), a flag that indicates whether the image comes straight from the satellite provider or if it results from the change detection processing, a pointer that indicates where the actual bytes of the raster can be found (those are not stored inside the database due to efficiency concerns).

By not storing the actual raster files in the database, one avoids the overhead of running a DBMS layer between the user and the actual data, which can be significant given the ACID constraints of a modern relational database system. In addition, the original images can be directly processed by the tools that use them without the need of further conversion, again evading the need for the overhead and inefficiencies of storing binary large objects inside a relational database.

In that same database, images that result from the multi-temporal pipeline processing are also stored; some of those those images (in 3-band RGB false color) are used for analysts consumption, for map making and made available to other government offices and NGOs, while some other images are used in further iterations in the multitemporal processing pipeline.

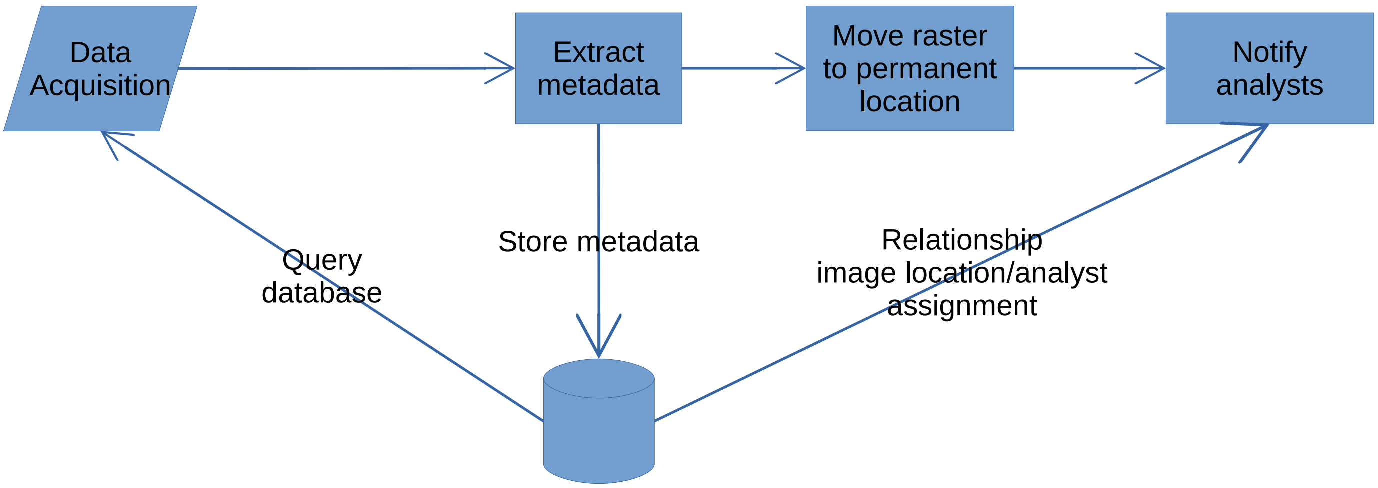


Fig. 4. Process model of the Amazônia SAR processing pipeline

The database contains a table - tb_divisao_amazonia_cim - that represents the grid of what is called the BCIM ("Base Cartográfica Contínua do Brasil", or "Continuous Cartographic Base of Brazil"), which is based on an international standard called "International Map of the World", or the Millionth Map [9]. There is a relationship between analysts (as stored in the table tb_responsavel) and the BCIM that maps the responsibility of each analyst to an area of interest.

The database diagram shows no relationship (in the Entity-Relationship Model sense) between the tables tb_imagem, tb_t0_desmatamento and tb_desmatamento. This is because that relationship is a spatial one; that is, the link between those entities is the intersections between the "geom" columns. Each record in the table tb_divisao_amazonia_cim corresponds to a square of approximately 27.6 by 27.6 kilometers, and is assigned to a single analyst (whom in turn belongs to one of the four Regional Offices of Censipam) via a traditional E-R foreign key and whose data is stored in the table tb_responsavel as shown in Figure 3.

The indexing system records the footprint of each image, and stores it as a geometry column in the tb_imagem table. The system decides which analyst - each of whom belongs to a Regional Office - must review and process the image by finding which record in the tb_divisao_amazonia_cim contains the geometric centroid of the geometric footprint of the image.

When a new image arrives, after it is processed and changes are detected by the pipeline, the analyst who is responsible for the area can be alerted, and may proceed to manually confirm - or discard - any changes in the observed terrain. The analyst then draws a deforestation polygon and save it as a new record in the tb_desmatamento table if it was not already registered in the tb_t0_desmatamento. At a later stage, the deforestation polygons in tb_desmatamento are merged and dissolved in the table tb_t0_desmatamento.

## IV. The Image Cataloging and Processing Pipeline

The processing pipeline, illustrated in Figure 4, starts when a new image is made available by the satellite operator (either a private business or a government agency), normally via an FTP server. A scheduled job runs automatically every 30 minutes to execute a bash script that reads the contents of the operator's server. The list of filenames from the remote server is matched against the database to validate if there are any images that were not yet downloaded. If so, the script downloads the images to a staging directory. Then, still without human intervention, the script starts a Python program that uses the library MetaGETA Crawler [10], which scans this staging directory, extracts the necessary data about the images, such as projection type, datum, corner coordinates, centroid coordinates, timestamp of collection, ground dimensions (X and Y) represented by each pixel, orbit direction, image file name, number of lines and columns of data, sensor type, type of polarization (if any) and size of ground area represented by the image.

After that, this Python program stores the extracted information (the image metadata) in the database and moves the images to their permanent storage area. Still without human interference, for each of the newly stored images, the program selects other previously acquired/stored images with the same geometry of acquisition (the same area, same view angle, and same orbit direction, beam mode, imaging mode, polarization, and look direction) as the current one, up to a number of seven. The file names of this stack of images are written to a XML file, which will be used in turn to instruct the next step of the pipeline how to process the images. The attributes (metadata) of the images that are stored in the database are shown in the table tb_imagem in Figure 3. Here the Python program finishes its execution.

That XML file is stored in a shared network folder, and its presence is an indicator to the next stage in the processing chain, which is shown in Figure 5.

That next stage is an IDL (Interactive Data Language) program (watchdog) that monitors the shared folder in search for these XML files, and processes the images using Harris Geospatial Solutions' ENVI software with SARscape module. This program can run on any number of workstations, thus enabling application level parallel processing and improving the speed of detection. That IDL program is specific to SAR

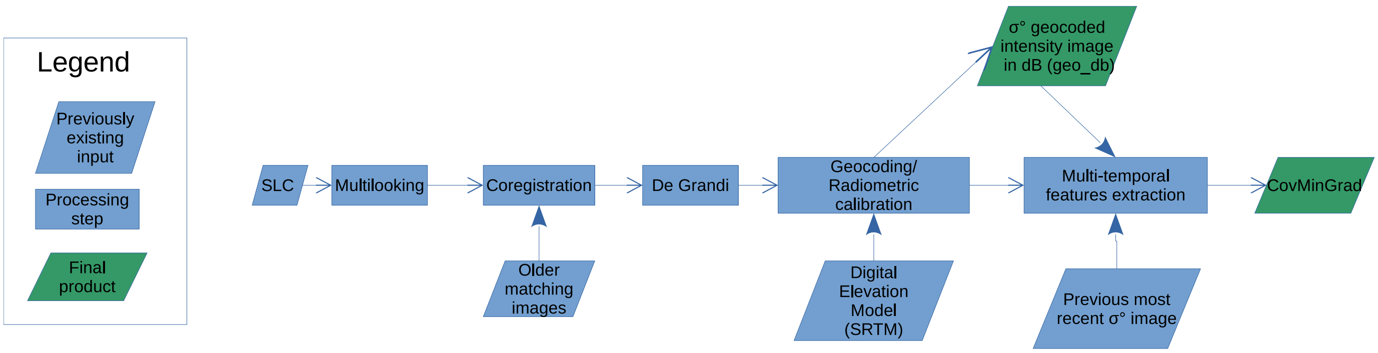


Fig. 5. Detail of the SAR processing in the image processing pipeline

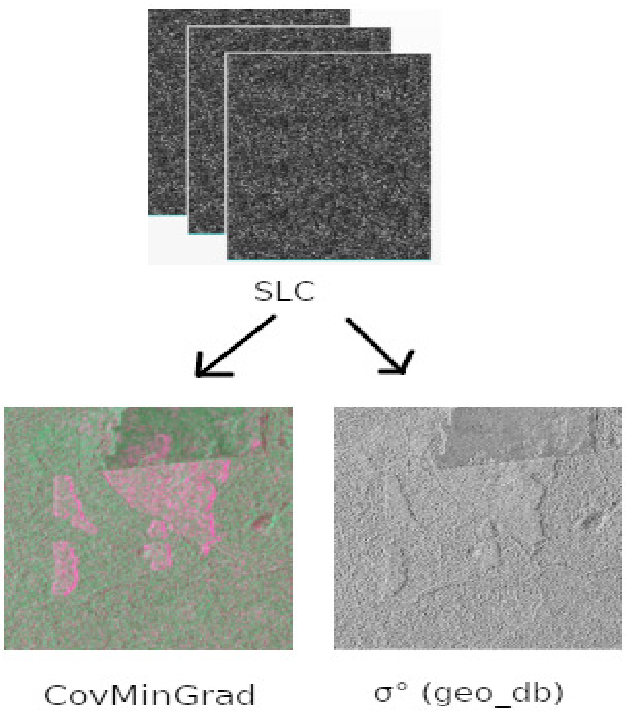


Fig. 6. Original image and resulting products

data; thus, the image processing cannot proceed if the source does not consist of SAR raster imagery.

This program reads that XML file, and applies a process of temporal change detection using the images named in it until level 3 of processing (that is, geocoded terrain).

First, the Single Look Complex (SLC) data is taken and passes through a basic multi-look filter which reduces noise at the cost of spatial resolution. If there are other images of the same area (up to seven), those are co-registered along with the output of that first multi-look filter. If there is only one or two images available for the same area (which is determined previously by querying the database for adjacent imagery), then the stack of co-registered images (or the original image, if there are no other images of the same area) is input to a Frost [11] speckle reduction filtering; if there are more images, the stack of co-registered images is fed to a change detection filter as first described by De Grandi, Lee, Leysen and Schuler [12]. Afterwards, with DEM information, the output of these filters (either De Grandi or Frost, depending on availability of multitemporal data of a given area) is geocoded, and radiometric calibration is performed on it.

From the radiometric calibration, a single band $\sigma^0$ (Sigma-Nought) image is generated. This image is called geo_db after its content, which is a representation of the strength of the reflected radar signal expressed in dB, as a signed 32 bit float. Data in this format can be used to compare images acquired by different sensors or in different modes by the same sensor (although they still must have the same spatial resolution). This image is stored in the shared drive, and its metadata is stored in the table tb_imagem along with the other images.

Finally, if there is a Level 1A image with the same characteristics (orbit direction, view angle, view side) as the current image, the coefficient of variation (“Cov”) between the current image and the previous one is calculated in order to detect changes in the viewed area, and minimums (“Min”) and gradients (“Grad”) are calculated in order to do color composition for the consumption of the analyst responsible for that area. This last step generates a new RGB (3 band, 8 bits per pixel) image, with the coefficient of variation mapped to the R channel, minimum to the G channel, and gradient to the B channel, between the last and second-to-last image of the studied area. For that reason, this image is called CovMinGrad; it is stored in the shared network drive in ordinary GeoTIFF format, and its metadata is recorded in the database, in the table tb_imagem, along with the original, Level 1A images. This whole process is executed automatically with the help of the SARscape module for ENVI, with code written in IDL to automate the processing steps.

It is important to note that this whole process of image retrieval, metadata extraction, change detection is done without any user interaction at all. There is no “user interface” in the traditional sense; the whole process is automated. The user (analyst) interacts with the system only after she is notified that there is a new detection image.

After the final CovMinGrad image is saved on disk and its metadata stored in the shared database, the system searches in the database table tb_divisao_amazonia_cim the record that intersects or contains the boundaries of the new area; the analyst responsible for that area is then notified by e-mail about the availability of the new image. The analyst then can confirm if the changes detected by the image processing are really caused by deforestation. If so, the polygon that marks the newly deforested area, drawn by the analyst, is stored in the database table tb_desmatamento, which will in turn, at the end of each processing cycle, be used to expand the baseline deforestation polygons stored in tb_t0_desmatamento. The CovMinGrad image appears to the analysts as a false color image, with shades of red as indications of possible deforestation, as shown in Figure 6.

The availability of a new Level 1A image of the same area that is suitable for co-processing is in a 30 days interval. This is because the multitemporal processing must be done with images of the same ground area, same orbit direction, same view angle and same view side.

A COSMO-SkyMed SLC image takes about 8 seconds to be acquired by the satellite sensor. Then, in the scenario where images are obtained by Censipam from an FTP server by the image provider, the image is downloaded from the satellite to the provider. It is then processed to the level 1A - that is, an image in which the raw in-phase and quadrature data are focused, weighted and radiometrically equalized.

Then, since the download script checks for new images availability every half an hour, soon after the image is downloaded. It takes 5 minutes to download a 1.8 GB image at 55 Mbps. Then, the indexing process (that is, extraction and storage of metadata and storage of image data to its permanent location, as described in Figure 4 takes 2 minutes; then the process of multitemporal feature extraction can begin if there are enough correlated images. However, if the provider makes more than one image available in a single batch, the cataloging process may start only after all images are downloaded, which may take up to 6 hours.

The processing of a series of 3 correlated Level 1A SLC COSMO-SkyMed to generate a pair of geo_db ($\sigma^0$) and CovMinGrad, shown in Figure 5, was measured to take anywhere between 29 minutes, if the images are already in the local storage of the processing machine, to 144 minutes, if the images must be obtained from a shared Local Area Network (LAN) drive.

The generated geo_db and CovMinGrad images, if any, are stored in the same database as the original, Level 1A images, and they are dealt with by the same script that catalogs the original images, which also takes 2 minutes per image.

This generated data is an important complement of INPE's DETER systems; the PRODES data, and the resulting polygon is used to feed other environmental alert systems.

## V. Conclusion

This automated process leads to much faster detection of deforestation if compared to manual sorting and selection of suitable images, input of processing parameters, and distribution of workload among the analysts, which allows Censipam to generate deforestation alerts to the agencies in charge of monitoring, inspecting these actions in a much more efficient and timely manner.

This data can also be used to feed other environmental monitoring systems, and to leverage environmental policy-making in order to understand and stop illegal deforestation.

Since there is no specialized user interface, and a human being enters the process only in the final stages of detection. Thus, analysts can keep up with the deforestation processes even though the monitored area is huge and human workforce is small.

The system is flexible enough to support many different image formats, and scalable enough that it can keep its current performance just by adding more processing workstations and more analysts, in a linear way.

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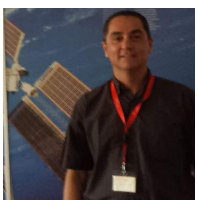

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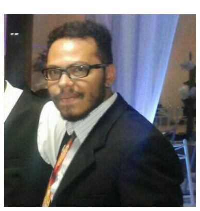

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